

# OFFICE OF TRANSPORTATION TECHNOLOGIES

## *The General Motors/HEV Is Targeted for Consumer Acceptance*

In September 1993, General Motors Corporation and the U.S. Department of Energy (DOE) signed a cost-shared, five-year Hybrid Propulsion Systems Development Program contract. The central goal of the project was to develop a production-feasible hybrid vehicle propulsion system as a step toward supporting Partnership for a New Generation of Vehicles (PNGV) goals.

Early in the project, marketing clinics were held to identify the critical product attributes necessary for a hybrid to gain consumer acceptance. Customer expectations included: a full-size trunk; ability to travel a significant distance in all-electric, zero-emission mode; a willingness to recharge the battery pack, if necessary; and a reluctance to spend more for an automobile with better gas mileage. Consequently, the principal objective was to design and develop a hybrid propulsion system to achieve better gas mileage in a full-size, full-power vehicle that could also be operated as an electric vehicle, use current manufacturing processes for commercial production, and adapt to the existing fuel infrastructure.



*The General Motors Gen2 Stirling series hybrid electric vehicle marks the completion of System Mile Vehicle development: the adaption of hybrid components to a conventional car.*

## *The Dual-Mode Series Hybrid Configuration Is Identified for the Marketplace*

Based on the consumer preference and marketplace sensitivity study, GM defined the vehicle technical specifications and selected a series configuration propulsion system due to its ability to deliver both high fuel economy and very low emissions. A "dual mode" series hybrid architecture was also chosen, which affords the opportunity to operate as a zero-emission vehicle (battery only) for short trips, or in full hybrid mode, or on the Hybrid Power Unit (HPU) only (at reduced performance).

## *The Stirling Engine Is Selected as the Hybrid Power Unit*

After investigating both the gas turbine and the Stirling engine, the choice of (HPU) was narrowed to the Stirling Engine. This engine derives its mechanical power from the expansion of confined hydrogen at high temperature. During the 'Stirling Cycle' hydrogen is compressed into a cooled chamber beneath the piston and then transferred to an externally heated second chamber above an adjacent piston. The heated hydrogen expands rapidly, generating energy that is used to drive the pistons in sequence. In the final step of the cycle, the expanded hot hydrogen is returned back to the cold chamber, compressed, and the cycle begins again. A Stirling engine is smooth and quiet, and can be designed to produce very low emissions since the combustion is "external" to the hydrogen working fluid.

## ***What Has Been Achieved?***

Overall, the project team demonstrated that it is possible to integrate a series-configuration hybrid propulsion system (with acceptable all-electric range) into a current model family sedan without sacrificing trunk space or passenger comfort and safety. Program technical achievements include the following:

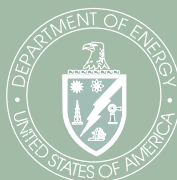
- The “dual mode” series propulsion system and associated accessories (electric power steering, electric air conditioning, and electric-assist/regenerative brakes) were successfully integrated into two Chevrolet Lumina sedans. One test vehicle supported controls development and the other supported HPU and battery pack development.
- A significant reduction in size and improvement in packaging and integration of the electric drive system was achieved. The electric drive system consists of the motor/gearing assembly, the Power Electronic Bay (PEB), and the associated electronic controls. Some of the most significant improvements included the integration of a reduced cost aluminum rotor, the development of a proof-of-concept coaxial drive, and 30% size reduction of the PEB.
- Advancements made on the HPU development included an enhanced heating system to increase the heat transfer effectiveness of the working gas, development of a coating method to reduce hydrogen permeation losses, and design of a hydride system for storage and replenishment of the hydrogen working fluid.
- A battery pack that incorporates spiral wound lead-acid battery technology was developed that satisfies rigorous requirements for power, size, cost, and manufacturability.

## ***Meeting the Challenges of Technical and Commercial Feasibility***

While the Program demonstrated good “technical feasibility” of the series hybrid electric propulsion system, meeting “commercial viability” objectives prove to be difficult. The projected propulsion system cost premium at program’s end was still well above that returned to the U.S. customer either in fuel saved or

additional resale value. Although the program succeeded in lowering system cost by applying “design for manufacture and assembly” techniques, while simultaneously focusing on improving reliability, more work needs to be done to fully address commercial challenges.

*For additional information, contact:*



**Roland Gravel**  
U.S. Department of Energy, EE-32  
1000 Independence Avenue, SW  
Washington, DC 20585  
(202) 586-9263  
[roland.gravel@ee.doe.gov](mailto:roland.gravel@ee.doe.gov)

FOR PROGRESS UPDATES ON THE HEV PROGRAM, ACCESS  
THE WEBSITE: [HTTP://WWW.OTT.DOE.GOV/OAAT/HEV.HTML](http://www.ott.doe.gov/OAAT/HEV.HTML)